MODIS/Snow Project
Semi-Annual Report (July - December 1993)
Submitted by D.K. Hall/974

Summary

During the last 6 months, the primary focus has been on development and validation of the snow-mapping algorithm (SNOMAP) using Landsat TM data, and writing up procedures for implementing the algorithm. Version 1.0 of the algorithm theoretical basis document (ATBD) was prepared and submitted. Preliminary code has also been written and turned in to the MODIS Science Data Support Team. Additionally, progress has been made on development of a more reliable passive-microwave algorithm for global snow mapping, and on snowmelt energy balance modeling. Plans have been formulated for a MODIS Airborne Simulator (MAS) flight during the winter BOREAS mission in Saskatchewan and for a validation effort using aerial photography over Glacier National Park, Montana during snowmelt conditions, concurrent with Landsat TM overpasses.

Currently four papers are in preparation: one for the August 1994 IGARSS Symposium, another for the February American Meteorological Society Conference, a third for the 10th International Northern Research Basins Symposium and Workshop, 28 August-3 September 1994, Spitzbergen, Norway, and the fourth for submission to a journal.

A. Task Objectives

The primary objective of the MODIS/snow work is to develop, test and validate algorithms that will be useful to map snow and sea ice cover globally, using MODIS calibrated radiances in an automated way. Additionally, other snowpack properties will be studied in order to improve our understanding of snowpack energy balance. Concurrent with the development of an algorithm to map snow using MODIS data, algorithms to map snow globally using passive microwave data are being validated and plans are being formulated to eventually combine visible, near-infrared and passive microwave data to optimize snow mapping and mapping of snow reflectance and water equivalent.

B. and C. Work Accomplished and Data Analysis

Work has been on-going in several different areas including: 1) developement of the algorithm theoretical basis document (ATBD), 2) acquiring and utilizing digital elevation data (DEM) to map snow by elevation zone in Montana, 3) BOREAS mission planning, 4) studying the utility of the MODIS Airborne Simulator (MAS) data for snow mapping, 5) validation of passive microwave algorithms to map snow globally, 6) planning validation flights during snowmelt in March and April 1994 in Glacier National Park, Montana, and 7) snowmelt energy balance modeling. Each of these topics will be discussed separately.

1) An ATBD was written and turned in to the SDST last summer. The ATBD details the current plans to develop accurate snow and sea ice mapping algorithms. Background information on prior efforts to map snow and sea ice is given. The algorithm that is currently envisioned to be used to map snow, SNOMAP, is described. The algorithm is being developed using TM data. A thresholding approach is used. A 10 May 1992 TM scene which was analyzed in detail by Walter Rosenthal/UCSB was used to test the results of SNOMAP. Results were found to compare well with Rosenthal's results for pixels that were at least 72 percent covered by snow.

The ATBD has been sent to three non-Goddard and four Goddard scientists for review. The document is now being revised prior to being sent out for external, peer review in Feburary.

2) DEM data have been acquired of most of Glacier National Park, Montana. These data are currently being processed into a form that will permit them to be registered to available 14 March 1992 TM data. The TM scene covers a variety of surface-cover types and also contains some clouds. The area was mostly snow covered at the time of data acquisition. The SNOMAP algorithm will be run on the TM scene before and after registration with the DEM data. Snow cover by elevation zone will be measured. Differences found in results of the algorithm with and without the DEM will be compared.

3) A flight of the MAS on the ER-2 aircraft is planned during the winter BOREAS mission to be held during the week of 6 Feburary 1994 in Prince Albert National Park, Saskatchewan. The MODIS Land Group has an approved BOREAS project. Data will be obtained from the MAS, passive microwave and gamma-ray sensors of snow extent, reflectance and depth. The utility of the MAS to map snow in heavy forest cover will be investigated concurrent with the ability of the passive microwave sensors to map both snow extent and depth through dense forests. Meetings have been held with the Canadians and other BOREAS investigators to plan the experiment.

4) MAS data from spring 1992 are currently being processed. During a test flight of the ER-2 aircraft in May 1992, data sets were acquired for the MODIS snow project over the Sierra Nevada Mountains. The SDST has been re-calibrating the MAS data from 1992 and plans to distribute them in late January 1994. MAS data will allow an improved analysis of the utility of the thermal-infrared bands for snow identification.

5) A study is being conducted by Jim Foster/974 and others in order to compare snow cover and snow mass outputs from general circulation models (GCMs). Validation of the ability of GCMs to represent accurately snow cover and snow mass distributions is vital for climate-change studies. Snow output from six GCMs was intercompared for the period 1979-1988 for both North America and Eurasia, in an effort to assess the magnitude of spatial and temporal variations that exist between the models. Passive microwave snow data from the Nimbus-7 SMMR and visible snow data from NOAA observations were used to gauge the capability of the models in reproducing actual observations. Preliminary results indicate that the models represent intra-annual and inter-annual snow cover distributions fairly well. For example, the United Kingdom GCM is within about 5 percent of the snow cover values measured from the NOAA data during the winter months. The paper by J. Foster et al., written for the American Meteorological Society Conference, to be held 23-28 January 1994, in Nashville, TN, is Appendix 1 of this report.

6) It is necessary to test SNOMAP under a variety of surface conditions, and to understand the conditions under which errors occur, and to measure the magnitude of those errors. An initial effort to validate SNOMAP was mentioned above in connection with the 10 May 1992 TM scene of the Sierra Nevada. Additionally, plans are being formulated to have a series of aircraft overflights of Glacier National Park, Montana during snowmelt in March or April of 1994. There is a variety of surface conditions in the Park. It will be important to measure the accuracy of the results of the algorithm in snow-covered forests, lakes and mountains.

Aircraft overflights using a sensor developed by Positive Systems of Kalispell, Montana, will be flown simultaneous with the Landsat overpasses. The aircraft data are both image and digital data. The resolution of the aircraft data will be approximately 5 m while the resolution of the TM data is 30 m. Limited ground observations will be made concurrent with the aircraft overflights and the satellite overpass. The aircraft sensor obtains data at approximately the following band centers: 450 nm, 550 nm, 650 nm and 850 nm (all with 80 nm band widths).

Digital aircraft data will be obtained of a portion of the Park on days of Landsat overpasses in March and April 1994. Following data processing, extent of snow cover will be measured using the digital data and also using the Landsat data. The aircraft data will be considered to be accurate, or the "ground truth." Thus, the accuracy of the Landsat-derived snow extent, using SNOMAP, will be measured relative to the aircraft data, and the error will be calculated.

Results from this experiment, combined with results from the 10 May 1992 TM scene will help us to analyze the accuracy of SNOMAP.

7. Glen Liston/USRA has been developing and testing a snowmelt energy balance model. Using the model, energy transfer processes during snowmelt can be modeled and are found to have significant variability at the micro and local scale. An paper to be presented at the 10th International Northern Research Basins Symposium and Workshop to be held this summer in Spitzbergen, Norway is Appendix 2 of this report.

D. Anticipated Future Actions

It is anticipated that work will continue in all of the areas discussed above. In the near future, there will be 2 aircraft overflights for algorithm validation purposes. The first will be during the BOREAS experiment over Prince Albert Park, Canada (NASA ER-2 with the MAS). The second will be low-level flights over Glacier National Park during snowmelt simultaneous with Landsat overpasses, for algorithm verification/validation. Following the data processing, most of the next 6 months will be spent analyzing and writing up the results of those experiments.

E. Problems/Corrective Actions

No major problems are noted at this time.

F. Publications

Three conference papers and one journal paper are in preparation. See second paragraph of Summary, above, and appendices, below, for details.

APPENDIX 1

INTERCOMPARISON OF SNOW COVER AND SNOW MASS IN NORTH AMERICA FROM GENERAL CIRCULATION MODELS AND REMOTE SENSING

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1. INTRODUCTION

General circulation models (GCMs) are essential tools for studies of the sensitivity of climate to a variety of processes, and for predicting the magnitude, timing and spatial distribution of regional and global climate and climate changes. Regardless of how sophisticated the models are, realistic results cannot be assured unless they are used with care and tested against results from observed data or other available data sets.

When there is a high degree of confidence that land surface data sets such as snow cover and snow depth

are reliable, they can then be used to validate the performance of the GCMs. Snow in particular is a good diagnostic for verification since, at least during accumulation, it is not diverted into streamflow or groundwater and so can be more easily accounted for than rainfall, for instance.

In this study how GCMs perform at continental scales will be quantitatively determined. Model results from several GCMs will be intercompared for North American, and the GCM outputs will also be compared with remote sensing (passive microwave and visible data) results. Quantifying the ability of GCMs to represent the global hydrologic cycle is important. This is the thrust of the Atmospheric Modeling Intercomparison Project (AMIP) which is using a ten-year period to intercompare model output from more than two dozen GCMs.

2. DATA SETS

2.1. GCMs

A number of modeling groups have agreed to share their GCM data for this study. The United Kingdom Meteorological Office (UKMO) in Bracknell, England: the Canadian Climate Centre in Downsview, Ontario; The National Center for Atmospheric Research in Boulder, Colorado; the Max Planck Institute (MPI) for Meteorology in Hamburg, Germany; the Goddard Institute for Space Studies, in New York; and the Goddard Space Flight Center (GSFC) in Greenbelt, MD have all provided snow mass and snow cover data. Most all of the available GCMs formulate snow in a similar manner. Precipitation falls as snow when the temperature of the lowest atmospheric level is below 0 C (Cattle, 1991). Snow thickness is calculated as a balance of snowfall, melting and sublimation (Cess et al., 1991). However, differences in factors such as physical parameterizations, grid size, and albedo result in different values of snow extent and snow mass. With the models, prediction of snow conditions is not hindered by the spectral limitations of remote sensors.

2.2. Passive Microwave Data

Since November 1978, the Scanning Multichannel Microwave Radiometer (SMMR) instrument on the Nimbus-7 satellite and the Special Sensor Microwave Imager (SSM/I) on DMSP satellite have been acquiring passive microwave data which can be used to estimate snow extent and snow depth. The algorithm developed by Chang et al. (1987) uses the difference between the SMMR 37 GHz and 19 GHz channels to derive a snow depth-brightness temperature relationship for a uniform snow field. This is expressed as follows:

$$SD = 1.59 * (TB18H - TB37H)$$

where SD is snow depth in cm, H is horizontal polarization, and 1.59 is a constant derived by using the linear portion of the 37 and 18 GHz responses to obtain a linear fit of the difference between the 18 GHz and 37 GHz frequencies. If the 18 GHz TB is less than the 37 GHz TB, the snow depth is defined to be zero.

2.3. NOAA Visible Data

Since 1966, the National Oceanic and Atmospheric Administration (NOAA) has prepared a weekly snow and ice boundary chart for the Northern Hemisphere. Monthly mean snow cover charts have been constructed from the weekly charts by deriving a subjective average of the weekly chart boundaries of each month. The areal extent of continental snow cover within this average monthly snow cover boundary is then measured and recorded. Each chart is the latest cloud-free snow observation of the particular area of the world.

The NOAA data set is subject to inaccuracies in locating snowlines due to prolonged periods of cloudiness in some areas and to analyst error in interpreting snow-free versus snow-covered terrain. However, the NOAA data are judged to be the most reliable of the available snow cover data sets.

2.4. Snow Depth Climatology

The U.S. Air Force Environmental Technical Applications Center (USAF/ETAC) at Scott Air Force Base in Illinois has assembled a global snow depth climatology (SDC) that is fully documented and is capable of being updated. This global snow depth climatology uses a mesh reference grid that divides each hemisphere into 64 equal boxes. Each base is divided into 4096 grid points that are about 46 km apart. For each month, every box and every grid point a snow depth value (taken to be representative of the middle of the month) is assigned based on results primarily from climatological records, literature searches, surface weather synoptic reports, and data obtained at snow course sites.

As with the NOAA data, this data set is not without sources of error. In a number of countries, summarized snow depth values are not always available to construct a snow climatology with even a fair degree of confidence. Nevertheless, because in many cases the snow depths have been directly observed, these data are deemed to be the most reliable of the limited snow depth data sets available.

For the purposes of this study North America encompasses all land areas between 10! and 170!W longitude. However, ice sheets are not counted in the snow cover calculations since the emphasis in this study is seasonal snow only. Thus Greenland is excluded as are islands such as Spitsbergen and some of the islands of the Canadian Archipelago.

3. RESULTS

The UKMO (UK) model, the MPI model and the GSFC (G1) model are run for the years 1979-1988 which is the time frame of the AMIP integrations. Due to space limitations these are the only models discussed in this paper. Although results from the other modeling groups mentioned above are similar. During these model simulations, sea ice extent and sea surface temperatures are prescribed and updated each month during the ten-year period based on observations. Monthly average snow output in terms of snow cover and snow mass are generated for the 1979-1988 period. The AMIP period is concordant with the SMMR record (1978-1987), and thus intercomparison between the AMIP modeled snow results and the passive microwave snow estimates are of particular interest.

Comparisons for a single year (1987) between the SMMR snow data and data from the UKMO Hadley model (year 1) demonstrated that GCMs were capable of representing observed snow conditions (Foster et al., 1993). The intent now is to see how snow output from different GCMs for a number of years, compares to snow conditions extracted from climatological data and from remotely-sensed observations.

NOAA visible data were used as the standard to compare the modeled snow extent output and the passive microwave estimates. For snow mass measurements, the US Air Force snow depth climatology was used as the base line to compare modeled snow mass and microwave derived estimates of snow mass. Snow mass is the derived snow depth times a specified density. For example, the density for the SMMR and USAF snow climatology is 0.3 g/cm3 and for the Hadley and UK models it is 0.25 g/cm3. The snow mass is given in units of 1013 kilograms, and the snow extent is given in units of 106 square kilometers. Snow extent in the area covered by at least a thickness of 1 mm of snow for the model data and approximately 1 cm for the NOAA data. Results are presented in Tables 1 and 2. Note, in the tables the average annual percentage difference (Jan-Dec) excludes data from Jun-Sep.

3.1. North American Snow Cover

Comparing NOAA measurements of North American snow cover to SMMR observations shows that SMMR underestimates the NOAA values for each month (Table 1). Spring is the season when the percentage differences are smallest. SMMR underestimates the NOAA values by 7.1% in March and 6.8% in April. February and March differences are similar (7.4 and 6.7%, respectively). The largest percentage differences, excluding the summer months of June through September, occur in October and November when SMMR underestimates the NOAA values by about 10%. The average annual percentage difference is 21.3%.

As with the SMMR data, the UK model snow cover results are smaller than the NOAA values for each month. During the winter period from December through March the percentage difference between the NOAA and UK results is less than 10%. October and November are the months when the differences are greatest (31.5 and 26.4%, respectively). The average annual percentage difference is 15.0%.

The GSFC-1 model snow cover values for North America compare very favorably with the NOAA values for all months with the exception of May and October. From November through April the percentage difference between the NOAA and GSFC-1 results in less than 7%. The average annual percentage difference is 9.6%.

Snow cover results from the MPI model also compare favorably with the NOAA results. The percentage difference between the NOAA and MPI results are less than 11% from November through May, and there is only a 1% difference for the months December through February. The average annual percentage difference is 9.0%.

3.2 North American Snow Mass

Concerning North American snow mass comparisons, SMMR-derived snow mass values are considerably smaller than the SDC values (Table 2). May and June are the only months when the percentage difference was less than 40%. From November through March the percentage differences are very similar, from 53.6 to 59.0%. The average annual percentage differences, excluding June through September, is 51.7%.

The UK snow mass values for North America are larger than the SDC values every month except February. The percentage differences are negligible in January, February and March (< than 4%). In October and May however, the differences are greater than 100%. The UK snow mass values are anomalously high during the summer months with absolute differences 50 x 1013 kg more than the SDC values. The average annual percentage difference is 50.4%.

With the GSFC-1 results, snow mass values when compared to SDC values are smaller from September through February but larger from March through June. April is the month of greatest snow mass according to results from this model. February and March are the only months when percentage differences between the SDC and GSFC-1 values are below 20%. The largest difference occurs in May (174%). The average annual percentage difference is 58.8%.

The MPI model generally underestimates snow mass when compared to the SDC snow mass values. April and October are the only mouths where the model values are larger than the SDC values. The closest agreement between the SDC results and the MPI results occurs in February (3.8%), and May is the month when the percentage difference is largest (39.8%). The average annual percentage difference is 21.3%.

4. DISCUSSION

One reason why passive microwave snow cover estimates are smaller than the NOAA measurements is related to the ineffectiveness of microwave radiation in providing information about shallow snow cover. When the band of snow near the southern limit of the continental snowline is sufficiently shallow (<3 cm) then the radiation upwelling from the ground may pass through the snowpack virtually unimpeded (Foster et al., 1993).

Difference in snow cover areal extent during the late fall and early spring between the NOAA, microwave and model data sets may be due to the positioning of the snowline in the boreal forests. The visible sensors on-board the NOAA satellites are unable to penetrate dense forest covers and monitor the underlying snow. With the microwave data the emissivity of trees, especially dense conifers, can overwhelm the scattering signal which results when upwelling microwave energy is redistributed by snow crystals. Thus, remotely-sensed snow observations may under-represent actual snow extent and snow mass values in forested regions. For the UK model data the consistent underestimation of snow cover is possibly due to the model physics packages, i.e., radiation, precipitation and boundary layer processes, forming snow too far to the north of where the actual snowline should be located. All three of the models have difficulty in reliably portraying snow cover conditions in October. This is the month when snow cover first advances southward, and it appears that the models have a problem in gauging when snow expansion should begin.

The boreal forests which stretch across the northern tier of North America is perhaps the physiographic region where most of the difference occurs between the snow depth measurements based on climatological data and those based on microwave observations. The most likely reason why the microwave data underestimates snow mass has to do with the effects of vegetation above snow fields. Forests not only absorb some of the radiation scattered by snow crystals, but trees are also emitters of microwave radiation. So in forested areas the signal received by a radiometer on-board a satellite is produced by a combination of media. Generally, the denser the forest, the higher the microwave brightness temperature despite the type and condition of the media underlying the forest canopy. Furthermore, because the canopy shields the snow from direct solar radiation the deepest snow accumulate in the densest forests (Foster et al., 1993).

In general, the models produce more snow mass than the SDC data or the SMMR data. The UK model overestimates snow mass in each month, but the differences between the SDC and UK results are especially noticeable during the summer and fall. The reason for this has more to do with where snow is permitted to accumulate and melt than it does with how snow accumulates and melts. During the summer in certain preferred high altitude and high latitude locations, where there exists a perennial snow cover, such as the Alaska Range, snow is evidently accumulating faster than it is melting, and hence the modeled snow mass is an order of magnitude higher than expected.

The G1 and MPI models both considerably underestimate snow mass in the colder months even though their snow cover estimates are in line with the observed values. Whether this is due to too little precipitation occurring in these models when the temperatures are below 0! C, or whether model temperatures are too warm to allow snow to adequately accumulate or to other deficiencies in the models needs to be further investigated.

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APPENDIX 2

Abstract submitted to

10th International Northern Research Basins Symposium and Workshop
NORWAY - 1994
Spitsbergen
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General Theme B: Hydrological and Biological Consequences of Climate Change in Northern Catchments

A MICROCLIMATE MODEL FOR NORTHERN APPLICATIONS

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A numerical atmospheric model based on higher-order turbulence closure assumptions is developed and used to simulate the local advection of momentum, heat, and moisture during snowmelt in heterogeneous terrain. The coupled model includes solution of the mass continuity equation, the horizontal and vertical momentum equations, a two-equation turbulence model, an energy equation, and a water vapor conservation equation. Atmospheric buoyancy considerations are accounted for, and a land-surface hydrology model, complete with full energy balance accounting, is implemented at the lower boundary. Such a physically-based model can be used to asses the local hydrological consequences of changes in landscape and climate. In addition, the model provides the opportunity to assess the consequences of computing areally averaged surface fluxes from grid-averaged atmospheric forcing, a common practice in current regional and general circulation model integrations for weather and climate simulation purposes.

In this study, the model is used to simulate energy transfer processes, during snowmelt, resulting from wind flow over alternating bare and snow covered ground. In addition, wind flow patterns and associated energy fluxes are simulated for the case of non-uniform topography with variable snow cover. Model integrations indicate that the variation in snowmelt process occurring at micro- and local-scales are significant, and argue for inclusion, or parameterization, of the subgrid-scale spatial variability of snow cover in regional- and global-scale land-atmosphere interaction models.

A MICROCLIMATE MODEL FOR COMPLEX TERRAIN

The initial phases of an atmospheric model based on higher-order turbulence closure assumptions has been developed to simulate the local advection of momentum, heat, and moisture in heterogeneous terrain. The model has been specifically formulated in an effort to solve problems of interest to researchers studying physical processes associated with micro and regional climate and land-vegetation-atmosphere interactions. The coupled model includes solution of the mass continuity equation, the horizontal and vertical momentum equations, a two-equation turbulence model, an energy equation, and a water vapor conservation equation. Atmospheric buoyancy considerations are accounted for, and a land-surface hydrology model, complete with full energy balance accounting and snow melt, is implemented at the lower boundary. The model is applicable to flows and land-atmosphere interactions occurring at microscale to mesoscale levels (20 m to 20 km), with a particular emphasis on resolving boundary layer processes.

The model equations and solution procedure designed to resolve the relevant physical processes and fluxes occurring in complex, real-world, situations. As an example, the model does not employ the hydrostatic approximation, commonly used in mesoscale models, and is thus able to resolve the vertical winds occurring in regions of high topographic variability. In addition, the model is able to define any lower topographic boundary configuration, without employing the coordinate transformation techniques commonly used in current mesoscale models. A preliminary version of the model has been shown to accurately resolve high shear boundary layer flows, even those involving separation and recirculation (Liston et al., 1993).

Several model applications are of interest to scientists studying land-atmosphere interactions and fluxes under non-homogeneous surface conditions. Examples of inhomogeneous surface conditions and flows, which the model will be able to resolve, include: interaction between forest and open clearings; flow through and over medium to tall vegetation canopies; flow over spatially varying soil moisture; local advection processes over open water leads in sea ice; snow accumulation and erosion in complex terrain; flow and snowmelt processes over patchy snow cover.

Such a physically-based microclimate model, capable of describing the advection and fluxes of momentum, heat, and moisture in complex terrain, can be used to asses the local biospherical, hydrological, and meteorological consequences of changes in landscape and climate. In addition, the model provides the opportunity to assess the consequences of computing areally averaged surface fluxes from grid-averaged atmospheric forcing, a common practice in current regional and general circulation model integrations for weather and climate simulation purposes .

PARAMETERIZING SUBGRID-SCALE SNOW COVER HETEROGENEITIES FOR USE IN GENERAL CIRCULATION MODELS

With its high albedo, low thermal conductivity, and rapid spatial variability, seasonal snow cover plays a key role in governing the EarthUs global radiation balance; this balance is the primary driver of the EarthUs atmospheric circulation system and resulting climate. Of the various radiation balance components, the location and duration of snow cover and sea ice comprise the most important seasonal variables. In the northern hemisphere, the mean monthly land area covered by snow ranges from 7% to over 40% during an annual cycle, making snow the most rapidly varying natural surface feature on Earth.

In light of the key role that snow plays in determining climate, it is important that general circulation models (GCMs), used to simulate climate, be capable of accurately describing the evolution of seasonal snow-covers. Recently, numerous studies have indicated that current representations of seasonal snow by GCMs are plagued with significant deviations from observations of middle and high-latitude snow cover. Typically, GCMs model snow accumulation and melt by applying simple energy and mass balance accounting procedures. These algorithms frequently neglect important physical processes such as snow albedo changes with temperature and time, and subgrid-scale temporal and spatial variability of snow-covered area.

We are developing a snow cover model suitable for use in GCMs which will explicitly include the influence of subgrid-scale snow cover variability. Our formulation will also account for the affects of different elevation zones, and differing vegetation types, such as forests and grasslands.

An initial focus of this proposal is to construct the seasonal evolution of snow-water-equivalent distribution curves for each of ten, 4! latitude by 5! longitude GCM grid boxes, located in the region bounded by 40!N to 48!N, and 87.5!W to 112.5!W. This area roughly extends from Minnesota and Wisconsin, to Montana and Wyoming, and includes wide variations in topography, vegetation, and climate. This zone also includes the upper region of the GEWEX GCIP Mississippi study basin, where snow moisture storage is an important feature of the basin hydrology. Formulation of the snow distribution curves will be accomplished by a suitable combination of snow cover depletion curves and an energy balance model which computes the potential snowmelt rate.

The generation of snow cover depletion curves is accomplished using NOAA National Operational Hydrologic Remote Sensing Center weekly snow cover products. As a secondary data source, we are utilizing the Chang et al., (1987) Scanning Multichannel Microwave Radiometer (SMMR) snow-parameter retrieval algorithm to reconstruct daily snow cover data. These data are used both in developing snow cover depletion curves, and for comparison with the NOAA Center snow cover data. In addition to assisting the development of high temporal resolution depletion curves, the satellite data allows the generation of similar curves for other regions of the globe, such as data sparse areas of the Arctic.

The potential melt rate is computed using an energy balance model developed for simulating the seasonal evolution of middle and high-latitude snow packs, when driven by observations and/or GCM simulated atmospheric forcing.

The produced snow distribution curves are then being used to parameterize the subgrid-scale snow distribution variability, and, as a consequence, improve key features of GCM simulations of the EarthUs radiation balance and land-surface hydrology. In the future, the parameterization will be tested using the Goddard Laboratory for Atmospheres GCM. This research comprises a crucial step in the development of next-generation GCM land-surface hydrology models which require improved realism in their parameterizations of unresolved subgrid-scale processes; processes of which snow cover plays a fundamental role.